

CLAIMS

1. Corrected parameter control method for a two-shaft gas turbine, characterized in that protection of the said turbine is provided by a first control loop which 5 controls the opening of the fuel valves to keep the temperature T_{fire} of the gas at the inlet of the first wheel of the said turbine and the fuel-air ration F/A within specified limits; the said control is provided in such a way that the set-point exhaust temperature T_X 10 is calculated as the sum of a reference temperature T_{Xbase} to which are added corrections relating to a single environmental or operating parameter which differs from the reference parameter.
2. Control method according to Claim 1, characterized 15 in that the said corrections are calculated by computer simulations of the said gas turbine, the said simulations being conducted by specifying the attainment of a maximum of the said temperature T_{fire} or a maximum of the said fuel-air ratio F/A , for each 20 condition differing from the reference condition.
3. Control method according to Claim 1, characterized in that there are four of the said corrections, the said exhaust temperature T_X being expressed by the following formula:

$$TX = TX_{base} + \Delta TX_{DPin} + \Delta TX_{DPout} + \Delta TX_{Hum} + \Delta TX_{PCNLP}$$

where

5 ΔTX_{Dpin} is the correction of the temperature TX due to the variation of the pressure drops in intake pipes with respect to a nominal value of 0 mmH2O,

ΔTX_{Dpout} is the correction of the temperature TX due to the variation of the pressure drops in exhaust pipes with respect to a nominal value of 0 mmH2O,

10 ΔTX_{Hum} is the correction of the temperature TX due to the variation of the relative humidity of the air with respect to a nominal value of 60%,

15 ΔTX_{PCNLP} is the correction of the temperature TX due to the variation of the speed of the low pressure shaft with respect to a nominal value of 100%.

4. Control method according to Claim 2, characterized in that the said exhaust temperature TX found by the said simulations is compared with the said reference temperature TX_{base} , in order to evaluate the said 20 correction terms appropriately, as differences.

5. Control method according to Claim 3, characterized in that a maximum exhaust temperature curve is generated for each considered speed of the said low

pressure turbine.

6. Control method according to Claim 5, characterized in that an equation for evaluating the said current exhaust temperature TX is:

5
$$TX = TX_{base}(PCNLP) + \Delta TX_DPin + \Delta TX_DPout + \Delta TX_Hum$$

where $TX_{base}(PCNLP)$ is the reference temperature found for the said specific speed of the said low pressure turbine.

10 7. Control method according to Claim 6, characterized in that there are two values of $TX_{base}(PCNLP)$, one related to a curve (21) of maximum temperature T_{fire} and one related to a curve (23) of maximum increase of temperature T_{rise} of the gas in the combustion chamber.

15 8. Control method according to Claim 7, characterized in that the said two maximum values are, respectively,

$$TX_{maxTfire} = TX_{base_maxTfire}(PCNLP, PR) + \Delta TX_DPin + \Delta TX_Dpout + \Delta TX_Hum$$

$$TX_{maxTrise} = TX_{base_maxTrise}(PCNLP, PR) + \Delta TX_DPin + \Delta TX_Dpout + \Delta TX_Hum,$$

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where a dependence on the compression ratio PR is also expressed.

9. Control method according to Claim 8, characterized in that the said temperature curves $TX_{base_maxTfire}$ and $TX_{base_maxTrise}$ are provided in the form of two-dimensional tables, with the compression ratio PR and 5 the low pressure turbine speed PCNLP as independent variables.

10. Control method according to Claim 8, characterized in that a diagram of the said maximum temperature TX, shown as a function of the compression ratio PR which 10 enables the maximum Tfire to be attained, shows a set of curves (27), each for a specific value of speed PCNLP, the said curve (27) generally having an increasingly negative slope as this speed increases, and being always of the type decreasing with a rise in 15 the compression ratio PR.

11. Control method according to Claim 8, characterized in that a diagram of the maximum temperature TX, shown as a function of the compression ratio PR, which enables the maximum Trise to be attained, shows a set 20 of curves (29), each for a specific value of speed PCNLP, the said curve (29) generally having an increasingly negative slope as this speed increases, and being always of the type decreasing with a rise in the compression ratio PR.

12. Control method according to Claim 3, characterized in that the said correction Δ_{TX_Hum} depends on the specific humidity SH and is expressed as a function of a difference Δ_{SH} , defined as the difference between 5 the actual specific humidity and the specific humidity $SH_{60\%RH}$ at a relative humidity RH of 60% (in the same conditions of temperature and atmospheric pressure), according to the formula:

$$\Delta_{SH} = SH_{current} - SH_{60\%RH}.$$

10 13. Control method according to Claim 12, characterized in that there is a linear correlation (31) between the said Δ_{TX_Hum} and the said Δ_{SH} .

14. Control method according to Claim 13, characterized in that the said humidity $SH_{60\%RH}$ as a 15 function of atmospheric temperature can be found by interpolating the following values, where the temperature is expressed in degrees Rankine:

$$SH_{60\%RH} (T=419.67) = 0.000070;$$

$$SH_{60\%RH} (T=428.67) = 0.000116;$$

20 $SH_{60\%RH} (T=437.67) = 0.000188;$

$$SH_{60\%RH} (T=446.67) = 0.000299;$$

$$SH_{60\%RH} (T=455.67) = 0.000464;$$

SH_60%RH (T=464.67) = 0.000707;

SH_60%RH (T=473.67) = 0.001059;

SH_60%RH (T=482.67) = 0.001560;

SH_60%RH (T=491.67) = 0.002263;

5 SH_60%RH (T=500.67) = 0.003324;

SH_60%RH (T=509.67) = 0.004657;

SH_60%RH (T=518.67) = 0.006367;

SH_60%RH (T=527.67) = 0.008670;

SH_60%RH (T=536.67) = 0.011790;

10 SH_60%RH (T=545.67) = 0.015966;

SH_60%RH (T=554.67) = 0.021456;

SH_60%RH (T=563.67) = 0.028552;

SH_60%RH (T=572.67) = 0.037585;

SH_60%RH (T=581.67) = 0.048949.

15 15. Control method according to Claim 3, characterized in that the said correction DeltaTX_Dpin is expressed directly as a function of a measured pressure drop DPin.

20 16. Control method according to Claim 15, characterized in that there is a linear correlation (33) between DeltaTX_Dpin and the said Dpin.

17. Control method according to Claim 3, characterized in that the said correction ΔT_{X_Dpout} is expressed directly as a function of a measured pressure drop $Dpout$.

5 18. Control method according to Claim 17, characterized in that there is a linear correlation (35) between the said ΔT_{X_Dpout} and the said $Dpout$.

19. Corrected parameter control method for a two-shaft gas turbine, characterized in that the control of the 10 said turbine at partial loads is provided by a second control loop which controls the opening of a vent valve to keep the temperature rise T_{rise} of the gas in the combustion chamber (and consequently the fuel-air ratio F/A) within specified limits; the said control is 15 provided by means of sets of maps of the exhaust temperature T_X as a function of the compression ratio PR, obtained for each operating condition of the said gas turbine.

20. Control method according to Claim 19, 20 characterized in that a control curve is defined for each value of atmospheric temperature.

21. Control method according to Claim 20, characterized in that there are diagrams showing the

relation between the said temperature TX, for partial loads at a given speed of the low pressure shaft, and the compression ratio PR, each relation curve (37) being associated with a specified value of atmospheric 5 temperature, the said curve (37) generally having higher values as this temperature rises, and being of the type which decreases as the compression ratio PR decreases.

22. Control method according to Claim 21, 10 characterized in that the said curves (37) are reduced to a single curve (39), thus eliminating the dependence on the atmospheric temperature.

23. Control method according to Claim 22, 15 characterized in that the said curve (39) is obtained by the following mathematical transformation:

$$TTX = TX \cdot (518.67/TCD)^x$$

where

- TX is the actual exhaust temperature;
- 518.67 is a reference temperature;
- 20 - TCD is the exhaust temperature of the compressor, expressed in a unit of measurement compatible with that of the constant;
- X is a nondimensional exponent calculated in

such a way as to minimize the mean quadratic deviation between the values of TTX calculated in this way and the interpolation curve (39);

5 - TTX is the transformed exhaust temperature, in other words the reduced temperature.

24. Control method according to Claim 23, characterized in that the said curve (39), when the actual value of PR is known and after the application of the inverse of the said transformation, yields the 10 reference temperature TXbase, from which the set point is calculated for the controller of the said second F/A control loop.

25. Control method according to Claim 24, characterized in that the said exhaust temperature TX 15 is calculated by a linear approximation as the sum of the reference temperature TXbase to which are added corrections relating to a single environmental or operating parameter which differs from the reference parameter.

20 26. Control method according to Claim 25, characterized in that there are four of the said corrections, the said exhaust temperature TX being expressed by the following formula

$$TX = TX_{base} + \Delta TX_{DPin} + \Delta TX_{Dpout} +$$

$$\Delta TX_{Hum} + \Delta TX_{PCNLP}$$

where

TX_{base} is found by inverting the said transformation,

5 thus: $TX_{base} = TTX / ((518.67/TCD)^x);$

ΔTX_{Dpin} is a correction of the temperature TX due to the variation of pressure drops in intake pipes with respect to a nominal value of 0 mmH2O;

10 ΔTX_{Dpout} is a correction of the temperature TX due to the variation of pressure drops in exhaust pipes with respect to a nominal value of 0 mmH2O;

ΔTX_{Hum} is a correction of the temperature TX due to the variation of relative humidity of the air with respect to a nominal value of 60%;

15 ΔTX_{PCNLP} is a correction of the temperature TX due to the variation of the low pressure shaft speed with respect to a nominal value of 100%.

27. Control method according to Claim 26, characterized in that each correction term is 20 calculated by computer simulations of the gas turbine, the desired F/A ratio being specified, for each condition differing from the reference condition and at different partial loads, the said exhaust temperature

TX found by the said simulations being compared with the reference temperature TXbase, in order to evaluate the correction terms in the appropriate way as differences.

5 28. Control method according to Claim 27, characterized in that a set of curves (41), one for each given value of speed PCNLP, is shown in a diagram of the said maximum temperature TX as a function of the compression ratio PR.

10 29. Control method according to Claim 28, characterized in that an equation for evaluating the current exhaust temperature TX is:

$$TX = TX_{base}(PCNLP) + \Delta TX_{DPin} + \Delta TX_{Dpout} + \Delta TX_{RH}$$

15 where $TX_{base}(PCNLP)$ is the reference temperature found for the specific speed of the low pressure turbine.

30. Control method according to Claims 23 and 29, characterized in that the said exponent X is a function of the speed of the low pressure wheel.

20 31. Control method according to Claim 30, characterized in that the exponent X, for intermediate speeds PCNLP, can be calculated by interpolation of the values of X calculated at the speeds PCNLP considered:

if PCNLP = 105%, X = 0.323
if PCNLP = 100%, X = 0.33225
if PCNLP = 90%, X = 0.34
if PCNLP = 80%, X = 0.34425
5 if PCNLP = 70%, X = 0.351
if PCNLP = 60%, X = 0.348
if PCNLP = 50%, X = 0.3505.

32. Control method according to Claim 26,
characterized in that the said correction DeltaTX_RH is
10 calculated by considering:

- three ambient temperatures (very cold day, ISO standard conditions, very hot day);
- three levels of relative humidity (0%, 60%, 100%);
- load characteristics according to a cubic law.

15 33. Control method according to Claim 32,
characterized in that nine simulations are conducted,
the desired value of F/A being specified, in order to
achieve the reference level, the current values of TX
then being plotted on a diagram as functions of PR,
20 while a difference between the said diagram and the
base curves yields the said DeltaTX_RH, as expressed in
the formula:

$$\Delta_{TX_RH} = TX - TX_{base}.$$

34. Control method according to Claim 33, characterized in that the said values of Δ_{TX_RH} are plotted on the diagram as a function of the difference 5 Δ_{SH} between the current value of specific humidity $SH_{current}$ and the specific humidity at $RH = 60\%$, $SH_{60\%RH}$, which is the reference value, and thus

$$\Delta_{SH} = SH_{current} - SH_{60\%RH}.$$

35. Control method according to Claim 34, 10 characterized in that the said diagram shows two straight lines (43 and 45), rising with an increase in Δ_{SH} , in which a first straight line (43), valid where Δ_{SH} is less than 0, has a greater slope than the second straight line (45) which is valid where 15 Δ_{SH} is greater than 0, the two straight lines (43 and 45) passing through a point near the origin of the axes.

36. Control method according to Claim 26, characterized in that the said correction Δ_{TX_DPin} 20 is expressed directly as a function of the measured pressure drop $DPin$.

37. Control method according to Claim 36, characterized in that the following are considered:

- three ambient temperatures (very cold day, ISO standard conditions, very hot day);
- three pressure drops in the intake (0, 100 and 200 mm of water);

5 - load characteristics according to a cubic law.

38. Control method according to Claim 37, characterized in that nine simulations are conducted, the attainment of the desired value of F/A being specified, in order to achieve the reference level, the 10 current values of TX then being plotted on a diagram as functions of PR, the difference between the said diagram and the base curves yielding the said DeltaTX_Dpin, this being expressed in the formula

$$\text{DeltaTX_Dpin} = \text{TX} - \text{TXbase}.$$

15 39. Control method according to Claim 38, characterized in that the said values of DeltaTX_Dpin are linearly correlated (47) with the said Dpin, the said values increasing with a rise in Dpin.

40. Control method according to Claim 26, 20 characterized in that the said correction DeltaTX_Dpout is expressed directly as a function of the measured pressure drop DPout.

41. Control method according to Claim 40,

characterized in that the following are considered:

- three ambient temperatures (very cold day, ISO standard conditions, very hot day);
- three pressure drops in the exhaust (0, 100 and 5 200 mm of water);
- load characteristics according to a cubic law.

42. Control method according to Claim 41, characterized in that nine simulations are conducted, the attainment of the desired value of F/A being 10 specified, in order to achieve the reference level, the current values of TX then being plotted on a diagram as functions of PR, a difference between the said diagram and the base curves yielding the said DeltaTX_Dpout, as expressed in the formula:

15
$$\Delta TX_{Dpout} = TX - TX_{base}.$$

43. Control method according to Claim 42, characterized in that the said values of DeltaTX_Dpout are linearly correlated (47) with the said Dpout, the said values increasing with a rise in Dpout.

20 44. Control method according to Claims 35, 39 and 43, characterized in that a correlation for calculating the maximum exhaust temperature TX is:

$$TX = TTX(PCNLP, PR) / ((518.67/TCD)^{X(PCNLP)}) +$$

DeltaTX_RH (DeltaSH) +

DeltaTX_Dpin (Dpin) +

DeltaTX_Dpout (Dpout).

45. Control method according to Claim 1 or 19,
5 characterized in that the said two-shaft gas turbine is
provided with a dry nitrogen oxide (NOx) reduction
system.